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Nuclear Theory Group

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Research Activities

(I) A FEW BODY PROBLEMS

a. Technique[1] (T. Sasakawa and J. Horáček)

The method of continued fractions which is very efficient for calculations of the scattering as well as the bound state problems is further discussed. This method is very flexible and we can consider various versions. In any case for a given b_n we calculate a_n by the equation

$$a_n = b_n^2/(b_n - a_{n+1}) \text{ for } n = N,N-1,\ldots,2,1 \qquad (1)$$

starting from $a_{N+1} = 0$ at $n = N$. The binding energy of the system is obtained by solving an equation

$$a_n - b_0 = 0. \qquad (2)$$

Also using a_1 obtained from Eq.(1), we can calculate the scattering amplitude. In fact, Eq.(2) amounts to calculate the pole of the scattering amplitude.

b. Triton binding energy[2] (T. Sasakawa and S. Ishikawa)

The Faddeev equation with 34 channels for various realistic two-nucleon potentials (2NP) with and without Tucson-Merbourne (TM) three-nucleon potential is solved by the method of continued fractions extended to three-body problems.

We get the binding energies which are very close to the experimental value of 8.48 MeV, if we take the cut-off mass Λ of the πNN form factor to be 700 MeV.

c. Form factors[3] (T. Sasakawa, S. Ishikawa and A. Fukunaga)

The charge and magnetic form factors are calculated. With the three-body force and exchange currents, we get a good agreement with experimental result for the charge form factor of ^{3}He. For triton, the calculated contributions from isoscalar and isovector exchange currents almost cancel out, and as a result, we can not get a good agreement with experimental results.

d. Asymptotic normalization constants[4,5] (T. Sasakawa and S. Ishikawa)

Without a three-nucleon potential, the ratio of asymptotic normalization constants C_2/C_0 is at most 0.04. Inclusion of TM in the Faddeev equation makes C_2/C_0 increase about 10%. We find that there is a linear relationship between C_2/C_0 and calculated triton binding energy B_3 for various potential models. We get $C_2/C_0 = 0.0432 \pm 0.0015$, in good agreement with recent ETH experiment.

e. Other triton physical quantities (T. Sasakawa, S. Ishikawa, K. Soutome and K. Ikeda)

The charge radius: Inclusion of TM makes B_3 larger, and as a result, r_{ch} (^{3}H) smaller. The agreement with experimental results is remarkable. Momentum distribution: The momentum distribution is calculated. At low momentum ($q \lesssim 100$ Mev/c), the effect of TM manifests itself in low energy quantities such as the charge radius. At intermediate momentum, the effect of TM is within the experimental error. At high momentum ($q \gtrsim 400$ MeV/c), the effect of TM might be seen, since the D-state of triton is predominant in this region. However, the cross section is very small.

Enhancement factor κ of El sum rule: TM makes κ increase about 10%. Electron inelastic scattering from ^{3}He and y-scaling low: The analysis suggests the importance of including the ρ-meson exchange three-nucleon potential.

The manuscript for these results were already submitted for publication or being written.

f. Coulomb problem[6] (T. Sasakawa)

The exact theoretical treatment of Coulomb effect is one of difficulties in few-body nuclear physics, but highly desired by experimental physicists. Some progress were made in this problem.

g. Conference etc. (T. Sasakawa)

Above results were reported as invited talks at the following meetings: Korean Physical Society Annual Meeting, April 27 - 28, 1985, Tongko University, Seoul, Korea; Third International Symposium "Mesons and Nuclei", European Conference on Few Body Physics, May 27 - June 1, 1985, Bechyne, Czechoslovakia[3]; The Tenth European Symposium on the Dynamics of Few Body Systems, June 3 - 6,

1985, Balatonfured, Hungary; International Workshop on the Dynamics of Few Body Systems, June 10 - 14, 1985, Hungarian Academy of Science, Budapest, Hungary; International Symposium on Few Body Method and their Application in Atomic, Molecular and Nuclear Physics and Chemistry, Aug. 4 - 10, 1985, Nang-Nin, China; Tsukuba International Workshop on Deuteron Induced Reactions and Polarization Phenomena, August 22 - 23, 1985 Tsukuba University, Japan[5]. Also invited talks were given at Seoul University, April 29, 1985; Korea University, April 30, 1985; University of Basel, June 17, 1985; Eidigenoessische Technische Hochschule Zurich, June 18, 1985; Kernforschungszentrum Karlsruhe, June 19, 1985; Ruhr Universität Bochum, June 21, 1985.

h. Estimate of the pionic contribution to very forward electron scattering from ^{3}He by surprisal analysis[8] (Y. Kawazoe and T. Tsukamoto)

Surprisal analysis is applied to the very forward electron scattering data on ^{3}He, for which the three-body theory fails to explain the excitation function. This discrepancy is often attributed to higher momentum components in the wave function of ^{3}He. An explicit expression for the final state densities including the nucleon and pion degrees of freedom is proposed. The present surprisal analysis succeeds in reproducing the experimental data without calling upon higher momentum components and suggests that even in the so-called quasielastic scattering region, not only nucleons but also a considerable number of pions are emitted in electron scattering.

(II) NUCLEAR REACTIONS

a. Test of Q-space Approximation in Nuclear Response Theory (S. Yoshida and S. Adachi)

The electric monopole states are solved in TDA with a separable interaction taking into account the continuum. These results are compared with the Q-space approximation, in which the configuration space is discretized by using the harmonic oscillator basis, and the continuum is taken into account via the escape width. The Q-space approximation is found to be very good.

b. Pre-equilibrium Emission of Nucleons from Giant Resonance States (S. Yoshida and S. Adachi)

Those highly excited states as giant resonances, deep hole states or isobaric analog states, which are produced as residual states by direct reactions, decay emitting nucleons. These nucleons may come directly from configurations in the highly excited states, but at least some parts come from more complicated states; compound nucleus or pre-equilibrium stage.

The pre-equilibrium emission of nucleons is treated by applying the theory developed by Nishioka, Verbaarschot, Weidenmüller and Yoshida. The emission cross section is expressed in a simple form.

c. The E2 Strength Distribution in ^{6}Li Studied by the (e,d_0) Reaction[9] (H. Taneichi, H. Ueno, K. Shoda, Y. Kawazoe and T. Tsukamoto)

Angular distributions have been measured for the ^{6}Li(e,d_0) reaction in the excitation energy range 10 - 28 MeV. The differential cross sections are decomposed into E1 and E2 components on the basis of a simple cluster model. The E2 strength deduced using a virtual photon spectrum is spread over the entire energy region studied. This strength reflects isoscalar E2 excitations in ^{6}Li. The E1 strength, which results from isospin mixing, shows no significant structure.

d. Constraint on $\sqrt{E}$ and Exciton Number (T. Tsukamoto, T. Honda, H. Matsuzaki and C. Ishii)

It is shown very convincing that the second constraint λ_2 introduced by Alhassid, Levine, Karp and Steadman in their surprisal analysis of heavy ion collision data reflects the constraint on the exciton number n_x. Arguments are based on Williams' state density formula for exciton model. Ericson's formula is also considered.

e. Spin Cutoff Parameter for the Exciton Model (T. Tsukamoto)

In order to estimate the angular momentum dependence of the state density for the exciton model, the spin cut off parameter for a noninteracting harmonic oscillator shell model (HOSM) is computed. A simple but useful estimate is obtained. A simpler estimation based on the level density formula of Williams is also given by introducing the "approximation of restricted population " (ARP). The spin cut off parameters for HOSM and ARP are functions of not only the exciton number n_x but also of excitation energy E_x. The ARP reproduces the average behavior of HOSM. ARP provides an improved version of the formula for the spin cut off parameter based on the equi-distance model.

(III)HEAVY ION COLLISIONS

a. Dynamics of Heavy Ion Fusion Reactions (N. Takigawa and K. Ikeda)

We extended our studies of the previous year on the effects of intrinsic vibrational modes of excitation on the fusion cross section in the scattering between medium-weight heavy ions. The new achievements during 1985 are as follows.

1. We proved that the simplified coupled channel equations, which do not explicitly treat the angular momentum problem and which are often used in this research fields for qualitative arguments, can be derived from the original coupled channel equations by using several completeness relations concerning the Clebsch-Gordan and the Racah coefficients. The underlying assumption is to ignore the change of the centrifugal potential barrier due to intrinsic excitation.

2. The two phonon states of a vibrational mode of excitation introduces an extra enhancement of the fusion cross section at energies well below the s-wave potential barrier in addition to the enhancement due to one phonon state. Near the barrier, to the contrary, they reduce the enhancement.

3. The extra effects of states of more than three phonons are small.

4. The pre-fusion excitation is considerable for the 2^+ vibration due to long range Coulomb excitation, and moderates the enhancement of the sub-barrier fusion cross section.

5. The system dependence of the enhancement of the sub-barrier fusion cross section has been analyzed by using the simplified coupled channel equations. We took ^{58}Ni + ^{58}Ni and ^{74}Ge + ^{74}Ge as an example and assumed that the first 2^+ state of ^{58}Ni and ^{74}Ge is the one-phonon state of the vibrational mode of excitation in these nuclei. This model reproduced the experimental discovery that the sub-barrier fusion cross section is much more enhanced in the ^{74}Ge + ^{74}Ge system than in the ^{58}Ni + ^{58}Ni system. The ordering of the absolute magnitude of the fusion cross section could not, however, be explained by this model.

b. Large Mass Drift in Low Energy Heavy Ion Collisions (M. Abe)

We analyzed the data at GSI for ^{238}U + ^{16}O, ^{27}Al, ^{48}Ca, ^{45}Sc, ^{48}Ti, ^{58}Fe, ^{64}Ni, and ^{89}Y, where yields with large mass drift are observed for the targets heavier than Ca. We showed that whether there appear yields with large mass drift or not can be related to the position of the Businaro-Gallon peak.

c. Quantum Tunneling in Multi-dimensional System and μCF (N. Takigawa and B. Müller)

We considered the coupling between collective and intrinsic degrees of freedom of a many-dimensional quantum system. We gave a criterion for the validity of the adiabatic approximation in tunneling processes and derived an equation for the "lag" of the intrinsic wavefunction with respect to the adiabatic ground state. We presented solutions for several simple cases. We suggested that the lag reduces the sticking probability of muon in the problem of muon catalysed fusion between d and t. It thus gives a clue to resolve one of the current problems that the conventional adiabatic approximation predicts too large sticking probability.

(IV) INTERMEDIATE ENERGY PHYSICS

a. Dynamical Six-quark State and the EMC Effect (T. Uchiyama and K. Saito)

The EMC effect is that the nuclear structure function (per nucleon) observed in the lepton deep-inelastic scattering is significantly different from that of a free nucleon. The Fermi motion of nucleon in nuclei cannot explain this phenomena. To do so, we propose a dynamical six-quark state which exists

in the short range part of two nucleons inside nuclei. This state is in pre-equilibrium process to the so-called six-quark cluster. This idea is compatible with the conventional nuclear physics. Moreover, it satisfies the new scaling rule derived from the SLAC experiment by Daté et al. We assume simple quark distributions in the exotic state and express the nuclear structure functions in the convolution form. Using this model, we study the EMC effect and structure functions at $x \gtrsim 1$. Our model well reproduces the experimental data. The obvious difference between the EMC and SLAC E139 data is also investigated.

b. Response Function of Quasielastic Electron Scattering in the Relativistic Approach[17] (T. Maruyama)

G. Dang and N. Giai assert that the longitudinal and transverse response function S_L and S_T of quasielastic electron scattering are explained with σ-ω model using the Fŏldy-Wouthuysen transformation. Moreover, L. Celenza et al. maintain the medium-modification of nucleon form factor is important too.

However, their calculations adopt many approximations. We perform the fully relativistic calculations and discuss the validity of these models. We find it difficult to reproduce the experiments within the framework of these models.

(V) MATHEMATICS

a. Number of Possible Algorithms[18] (T. Tsukamoto, H. Matsuzaki and Y. Kawazoe)

The number of binary trees for a fixed number of leaves is derived in a closed form. The result gives the number of possible algorithms of executing an expression composed of binomial operators. This is also the number of possible immediate constituent structures for a sentence with fixed length.

Publications

1) Method of Continued Fractions for on-and-off shell t-matrix of local and non-local potentials, J. Horáček and T. Sasakawa, Phys. Rev. C 32 (1985) 70.
2) Triton Binding Energy and Three-Nucleon Potential, T. Sasakawa and S. Ishikawa (Acta Physica Austriaca) 1, (1986) 3.
3) Charge Form Factor of Three-nucleon Systems, T. Sasakawa, A. Fukunaga and S. Ishikawa , Czechoslovak J. Phys. B 36 (1986) 312.
4) Asymptotic Normalization Constants of $^3H \to n + d$ and Triton Binding Energy, S. Ishikawa and T. Sasakawa, Phys. Rev. Lett. 56 (1986) 317.
5) Wave Function of Few Nucleon System Related to Deuteron Induced Reactions, T. Sasakawa and S. Ishikawa, in The Proceedings of Tsukuba International Workshop on Deuteron Involving Reactions and Polarization Phenomena, ed. by Y. Aoki and K. Yagi (World Scientific, Singapore, 1986), p. 317.

6) Integral Equation for Coulomb Problem, T. Sasakawa in Rationale of Beings, ed. by K. Ishikawa et al. (World Scientific, Singapore, 1986), p. 291.

7) Effect of three-body force in ^{3}He and ^{3}H, T. Sasakawa, Proceedings of the Xth European Symposium on the Dynamics of Few-Body Systems, Hungary, ed. by P. Doleschall et al. (Hungarian Academy of Science), p. 71.

8) Estimation of the pionic contribution to very forward electron scattering from ^{3}He by surprisal analysis, Y. Kawazoe and T. Tsukamoto, Phys. Rev. C33 (1986) 275

9) The E2 strength distribution in ^{6}Li studied by the the (e,d_0) reaction, H. Taneichi, H. Ueno, K. Shoda, Y. Kawazoe and T. Tsukamoto, Nucl. Phys. A448 (1986) 315

10) Comparison of Exact and Approximate Time Developing Functions in the Statistical Theory of Nuclear Reactions, J. J. M. Verbaarshot and S. Yoshida, Z. Physik A322 (1985) 621

11) Application of Time-Dependent Mean-Field-Theory to Heavy Ion Collisions: Simple Example of an S-Matrix Calculation for Elastic Scattering, K. Ikeda, S. Yoshida and S. Yamaji, Z. Physik A323 (1986) 285

12) Transition from regular to irregular spectra in quantum billiards, T. Ishikawa and T. Yukawa, Phys. Rev. Lett. 54 (1985) 1617

13) Path Integral Approach to Multidimensional Quantum Tunneling, A. B. Balantekin and N. Takigawa, Ann. Phys. 160 (1985) 441

14) Angular Momentum Transfer in Heavy Ion Collisions as a Non-Equilibrium Process, K. Nishinohara and N. Takigawa, Proc. of the Kikuchi Summer School on Polarization Phenomena in Nuclear Physics.

15) Fission Viewed as a Transport Phenomenon; Possibility of the Pre-Fission Particle Emission, N. Takigawa, RCNP-P-80, p. 25

16) Effect of the Fermi Motion on Nuclear Structure Function and the EMC Effect, K. Saito and T. Uchiyama, Z. Physik A322 (1985) 299

17) Response Function of Quasielastic Electron Scattering in Relativistic Approach, T. Maruyama, RCNP-P-83, p. 171

18) Number of Possible Algorithms, T. Tsukamoto, H. Matsuzaki and Y. Kawazoe, in Rationale of Beings, ed. by K. Ishikawa et al. (World Scientific, Singapore, 1986)

Doctor Theses (March 1986)

D1) Effects of Three-Nucleon Forces on the Trinucleon Bound State, Souichi Ishikawa

D2) Level Statistics and Chaotic Motion, Tadashi Ishikawa

D3) Theoretical Study on the EMC Effect, Toshihiro Uchiyama

Master Theses (March 1986)

M1) Quasi Fission: mass asymmetric decay mode of dinuclear system in dissipative heavy ion reactions, Masanori abe

M2) Three-Body Force Effects on y-scaling in Quasi-Elastic Electron Scattering from ^{3}He, Kouichi Soutome